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The Causes of Maple Blight in the Lake States

LAKE STATES FOREST EXPERIMENT STATION
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FOREST SERVICE
U. S. DEPARTMENT OF AGRICULTURE

CONTENTS

Page

ACKNOWLEDGMENTS i

SUMMARY AND CONCLUSIONS 1

INTRODUCTION 2

DETECTION AND APPRAISAL SURVEYS 3

- Detection Survey 3
- Appraisal Survey 4

DEFOLIATION STUDIES 6

DISEASE STUDIES 9

INSECT STUDIES 11

ECOLOGICAL STUDIES 13

ACKNOWLEDGMENTS

The maple blight studies are an outstanding example of cooperative effort to resolve a crisis situation. Actually, so many individuals and organizations made major contributions that it is hazardous to try to enumerate them. We are attempting to do so and hope that we are not remiss and neglect any major contribution.

First, we wish to give credit to the research scientists and survey personnel whose work provided the results presented in this paper. The Station's detection and appraisal survey was conducted under the direction of Dr. Ralph L. Anderson, who was ably assisted by Dr. David W. French, Department of Plant Pathology, University of Minnesota, and Dr. Gene A. Hesterberg, Forestry Department, Michigan Technological University. The Wisconsin Conservation Department conducted intensive surveys for maple blight and the associated insects. They also collaborated with the Station in appraising the problem. Most of this work, done under the direction of Mr. Don Renlund, was accomplished by Mr. Stanley Banash. In Michigan Mr. Norman Smith of the Michigan Conservation Department collaborated with the Station by providing reports on possible blight areas received from the Department's field personnel and others cooperating in pest detection work.

Research to determine whether any pathogens were responsible for maple blight was conducted by Dr. David R. Houston under the guidance of Drs. A. J. Riker and J. E. Kuntz of the University of Wisconsin, Department of Plant Pathology.

Research on the role of insects in the maple blight problem was conducted by Drs. Ronald L. Giese and Joseph E. Kapler under the guidance of Dr. Daniel M. Benjamin of the University of Wisconsin, Department of Entomology. Dr. Roy D. Shenefelt contributed to the University's efforts by identifying insects.

Research on ecological factors was conducted by Mr. Darroll D. Skilling of the Station's staff, under the general supervision of Mr. R. A. Ralston. Consultation and advice were provided by Mr. F. H. Eyre, retired, a well-known authority on northern hardwood silviculture.

For various reasons, all of the above research studies included defoliation of maple. In addition, Dr. Gene A. Hesterberg of the Michigan Technological University studied the effects of defoliation.

Second, we wish to express appreciation for the financial support that made these studies possible. The Lake States Forest Experiment Station received contributions of $12,000 from the Northern Hardwood and Pine Manufacturers Association, $10,000 from the Maple Flooring Manufacturers Association, and $2,000 from the Birch Club. This $24,000 contributed by industry, plus appropriated funds made available by the Station, were the major sources of financial support used to initiate the studies. The Lake States Station in turn provided the University of Wisconsin with $12,000 to support their work on the problem. The Wisconsin Conservation Department also contributed substantial financial support needed to carry to a conclusion the studies conducted by the University of Wisconsin.

Third, we wish to express appreciation to the several groups that cooperated so effectively in facilitating development of a sound, coordinated program of study. At an action committee meeting in Wausau, Wis., in January 1958, the first steps were taken for organizing a research program. Participating in this meeting with the Forest Service and providing invaluable guidance were representatives of the Northern Hardwood and Pine Manufacturers Association, Connor Lumber and Land Company, Goodman Division of Calumet and Hecla, Inc., Kimberly-Clark Corp., Wisconsin Conservation Department, Michigan Conservation De-

partment, University of Minnesota, University of Wisconsin, University of Michigan, and Michigan Technological University.

A steering committee composed of representatives of the Northern Hardwood and Pine Manufacturers Association, the Maple Flooring Manufacturers Association, the Birch Club, and the Wisconsin Conservation Department provided effective guidance in making the formal cooperative arrangements for the financial support of the project by industry and in determining how these funds should be distributed and expended. Mr. Allan S. Haukom, Secretary-Manager of the Northern Hardwood and Pine Manufacturers Association, during the early period of the studies, and his successor, Mr. William A. McGraw, were particularly helpful to the Station in handling many of the details involved in such cooperation, including arrangements for a number of meetings in Green Bay, Wis., at which progress to date was presented by the research workers.

In conducting the studies, cooperation given by the University of Wisconsin on the insect and disease research was essential. The Goodman Division of Calumet and Hecla, Inc., also provided an essential service in making the maple blight area available to the researchers and in facilitating their use of the area.

SUMMARY AND CONCLUSIONS

In 1957 severe damage and mortality of sugar maple in Florence County, Wis., resulted in a strong cooperative research effort among Federal and State agencies and industry to determine its cause. Detection and appraisal surveys and insect, disease, and ecological studies were made. The following conclusions were drawn:

Much of the alarm about the maple blight problem at the time of its outbreak in Florence County, Wis., was based on the fact that the cause was unknown; hence, the possibility of a virulent pathogen that could cause sustained widespread devastation could not be ruled out. Since no virulent pathogen was discovered, the chances are that any future outbreaks of maple blight will be sporadic and rather localized, although damage in such areas could be severe.

All studies of the problem support the view that insect defoliation is the primary cause of maple blight. This conclusion indicates that sugar maple is much more susceptible to serious injury from a relatively limited period of defoliation than was previously considered to be true for hardwood species. This, the major finding of the maple blight studies, calls for a considerable reorientation in attitude toward defoliation of sugar maple. The studies also indicated that timing of defoliation is very important if serious damage is to occur. The defoliation must be early enough in the season so trees reflush, and it must be late enough so the reflush growth does not harden off at the end of the growing season. July to early August, therefore, is the critical period for maple defoliation.

With reference to the defoliating insects, the most significant finding is that the webworm does the damage but a population of leaf rollers is essential to the development of a webworm epidemic because it lays its eggs only in rolled leaves.

The research studies also showed that other factors contribute to the severity of maple blight damage. Armillaria root rot appears to increase the amount of postdefoliation mortality — mostly the mortality that occurs the second and third years after defoliation. Previously killed trees and stumps apparently provide the food base that seems to be necessary in order for Armillaria to aggressively attack living trees. Below-normal soil moisture levels increase the severity of maple blight symptoms. Hence, defoliation coincidental with a period of drought would result in somewhat greater damage than would occur under other conditions.

Maple blight damage is more severe in understocked stands and in stands composed primarily of sugar maple. Most likely low stocking and higher proportions of sugar maple favor buildup of the defoliating insects; therefore, the effect of these factors on blight development is a reflection of conditions favorable for high insect populations.

Evidence also suggests that fall frosts may be a very important factor. The reason for this is the killing of buds on reflush growth that is not yet hardened off. The timing and severity of fall frosts following defoliation and reflush may therefore seriously affect the severity of maple blight damage.

An important consideration is the action to be taken in future outbreaks of the complex of defoliating insects that lead to development of maple blight. Of the various factors affecting development of maple blight, only two lend themselves to what might be considered indirect control or prevention of outbreaks. These are stocking and stand composition. Efforts to maintain good stocking and, to the extent possible, a mixture of species would help to minimize the possibility of severe outbreaks of the defoliators and subsequent blight damage.

Since maple blight has developed in the past, it has to be assumed that similar outbreaks will occur in the future, although there is no way of knowing their frequency or extent. Past experience indicates that they are relatively rare. However, as has been shown by experience, local damage in such outbreaks can be very severe and no doubt would merit application of direct control measures. Since the primary cause of maple blight is insect defoliation, the obvious point at which to apply direct control is the defoliating insects. The relatively low populations of the insects during the maple blight research and in subsequent years has precluded pursuit of any research on various control techniques. The complex of insects involved and the rather extended period during which their various life stages emerge indicate that development of a relatively simple direct control measure may be very difficult. In any future outbreak of the insects involved in development of maple blight, especially the maple webworm, control development studies would merit research attention.

INTRODUCTION

In 1957 severe mortality and dieback of sugar maple appeared on an area in Florence County, Wis. Maple of all sizes from seedlings and small saplings to saw-log timber were dead, dying, or damaged (fig. 1). The alarmed owners asked several specialists to appraise the situation.

Although maple on the area had been severely defoliated by insects, forest entomologists seriously doubted that this was the primary cause. Other hardwoods on which defoliation had been studied did not die under similar circumstances, and also in some known situations maple had suffered seemingly similar defoliation without mortality. Forest pathologists could not detect any known disease but were of the opinion that a pathogen might be involved. Silviculturists did not note any physical factor that seemed to be the cause, but neither could they rule out this possibility.

Some of these specialists had long and extensive experience with northern hardwoods. All agreed that they had never seen such a situation before. It was particularly alarming because, without knowing the cause, there was no basis for estimating its potential for spread and intensification.

Since the cause was unknown, the problem was given the nondescriptive name of maple blight.

None of the research organizations in the region had adequate resources to undertake intensive studies of the problem. The hardwood industry offered to provide some of the financial support, and the Station assumed responsibility for coordinating the research. Representatives of the Station, industry, and universities met to analyze the problem and develop a program of research. Four areas were recognized as needing attention. These were: (1) An appraisal survey to determine distribution and rate of spread, if any, of the disease, (2) a study of ecological factors that might be the cause, (3) a study of insect relations, and (4) a study of possible disease organisms involved.

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FIGURE 1. — Salvage logging on maple blight area in Florence County, Wis.

The Station agreed to undertake the appraisal survey and the ecological study, supported in part by appropriated funds and in part by the industry-contributed funds. The Station also entered into a cooperative agreement with the University of Wisconsin under which the Station contributed funds to the University, and the University in turn assumed responsibility for conducting the insect and disease organism studies. The funds provided by the Station were not adequate to complete these studies. During the later phases, support was provided for the University by the Wisconsin Conservation Department. The Wisconsin Conservation Department and the Michigan Conservation Department also participated in the detection and appraisal survey effort.

The studies were begun in the spring of 1958 and are now completed. During that time the Station prepared three informal written progress reports, and three meetings were held at which the research workers gave forest land managers the results to date of their work. The primary purpose of this paper is to provide a final report, highlighting and summarizing the more important findings for forest land managers and particularly for those who contributed to and cooperated in work on the problem. Those interested in a more detailed and technical report are referred to University of Wisconsin Bulletin entitled "Studies of Maple Blight," which presents a detailed account of the insect, disease organism, and ecological studies.

Since the maple blight investigation involved several different studies, the body of this paper consists of five sections: one on the surveys and the others on the major areas of study.

With so many workers involved in these studies, a brief summary report cannot specify the precise contribution of each one. Therefore, this paper was prepared as an editorial report, with recognition to the major contributors given in the acknowledgments section and in footnotes rather than in a complex array of authorship for the various sections.

DETECTION AND APPRAISAL SURVEYS[1]

The severe damage caused by maple blight in 1957, plus the fact that the cause of the disease was unknown, indicated that surveys were needed to answer two questions: First, how extensive was the problem — that is, what was the current distribution of maple blight? Second, was the blight spreading and intensifying and, if so, how rapidly? Information on rate of spread and intensification would provide a sound basis for estimating the disease's potential for future damage and hence how much future research effort would be justified and how important it would be to apply any possible control measures.

There were two aspects to the survey program begun in the spring of 1958. One was a detection survey. Since the resources available were limited and also because the Wisconsin Conservation Department and the Michigan Conservation Department both had active and well-organized pest survey organizations functioning in the field, a separate survey for maple blight was not undertaken. Instead, the Conservation Departments in the two States, the National Forests, and interested private northern hardwood timberland owners were provided with instructions on how to recognize possible maple blight areas and how to report such areas through normal channels to the Lake States Forest Experiment Station. The Station then followed up by sending a pathologist who was familiar with maple blight to inspect areas reported to the Station.

The second aspect was an appraisal survey conducted by Station pathologists and collaborating University pathologists. Appraisal surveys to determine whether maple blight was intensifying or spreading were made on the original maple blight area in Florence County, Wis., and also on those new areas that were found in the detection survey.

Detection Survey

During the 1958 and 1959 field seasons 21 reports were received about areas suspected of having maple blight. Five of these were in the Lower Peninsula of Michigan, eight in the Upper Peninsula, and eight in Wisconsin. No reports of possible blight areas have been received since 1959.

Followup examination indicated that none of the Michigan areas had maple blight. In Wisconsin, however, two of the eight areas examined had maple blight. These were in addition to the original area of extensive and severe maple blight in Florence County (fig. 2). The two blight areas found in the course of the detection survey are very small and of minor importance. One, in Iron County, (T. 43 N., R. 1 E., sec. 20 and 35), consists of two small patches — 0.5 acre and 0.9 acre in size — with severe mortality. The second area, in Ashland County, consists of three small patches — 1 acre in T. 43 N., R. 2 W., sec. 6; 0.3 acre in T. 44 N., R. 2 W., sec. 22; and 1.2 acres in T. 42 N., R. 4 W., sec. 2.

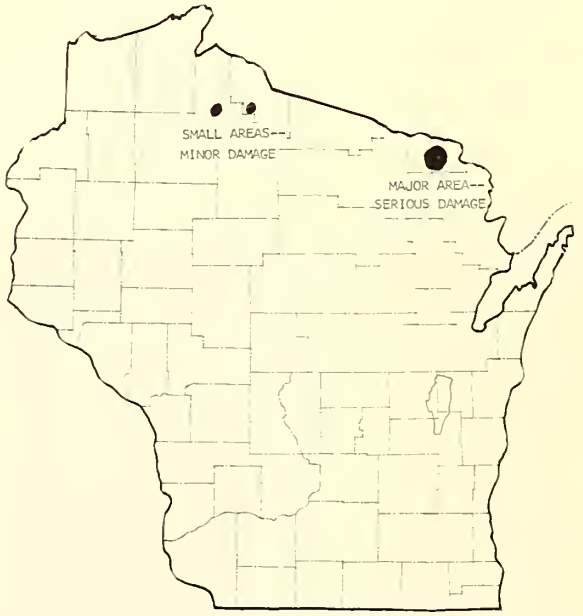

FIGURE 2.—Location of maple blight areas in Wisconsin.

Many of the other suspect areas proved to have maple dieback instead of maple blight. Maple dieback, which is widespread throughout the Lake States and the Northeast, is now causing some concern to land managers. It is regarded as distinctly different from maple blight, however; and care

[1] *Conducted by Dr. Ralph L. Anderson, Lake States Forest Experiment Station, Dr. David W. French, University of Minnesota, and Dr. Gene A. Hesterberg, Michigan Technological University, with the cooperation of the Wisconsin Conservation Department (Mr. Donald Renlund and Mr. Stanley Banash) and the Michigan Conservation Department (Mr. Norman Smith).*

was taken in the survey followups to distinguish between the two diseases. Dieback is generally limited to the larger overstory trees, progresses rather slowly, and seldom causes mortality. Maple blight, on the other hand, affects trees of all size classes, causes severe mortality, and has other distinctive characteristics such as profuse, epicormic sprouting on affected trees that have not been killed by the disease (fig. 3).

The results of the detection survey were encouraging. They indicated that maple blight was limited to three areas in Wisconsin and that in two of these areas the amount of timber affected was insignificant.

Appraisal Survey

The objective of the appraisal surveys was to determine whether maple blight was spreading outward into new areas and intensifying on those areas with affected trees. Because of substantial differences in the areas on which such surveys had to be made, two methods were used. In Iron and Ashland Counties, where the affected areas usually involved less than an acre, each area was studied intensively. The outermost limits were marked with paint to provide reference points. These were used in later re-examinations to determine whether the blight was progressing into previously unaffected areas. Then practically all living trees within the affected area were examined to determine when injury had first occurred and whether new injury or symptoms were developing — that is, whether the disease was intensifying. To determine when a tree was first injured, the point where a killed portion of the crown joined living tissue was located; then the annual rings laid down on the living portion since the other portion died were counted.

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FIGURE 3. — Maple saplings killed by maple blight. Damage and mortality of small trees is one characteristic of blight that distinguishes it from the more widespread maple dieback problem that is generally limited to larger overstory trees.

Although defoliating insects were not active on these areas at the time they were appraised, an effort was made to determine whether they had been defoliated by checking with Pest Survey personnel and examining such clues as might be found on the plot area; for example, growth rate on brush and understory trees was checked for any acceleration that may have occurred during periods of defoliation.

On the original extensive maple blight area in Florence County, Wis., a substantially different approach to the appraisal had to be made because of the large area involved and the greater complexities. Maple blight symptoms extended over an area of about one township, with concentrated severe damage in a number of local areas involving in aggregate about 1,000 acres and a scattering of lesser damage on intervening areas (fig. 4). Also, the preliminary investigations of the problem had been made on this area; and nearly all of the early research was conducted here. Most of the research workers had established permanent study plots on which they rated the severity of blight damage on affected trees. Thus, information on future intensification of blight would be obtained as a matter of course in the process of the research studies. Most of the survey effort, therefore, was devoted to determining whether the blight was spreading into previously unaffected areas.

The first step was a preliminary aerial survey to roughly map in the areas with obvious maple blight symptoms and to orient the survey crew on the area in general. This was followed by ground mapping conducted by two-man survey crews. The survey crews ran numerous transect lines, starting

in areas of known blight damage and continuing the line outward until they had gone some distance beyond any evident blight symptoms. As the transects were run, the presence or absence of blight and estimated intensity were recorded to provide a basis for later re-examination of the same transects to note any change. Emphasis was placed on locating the outer limits of areas with a low prevalence of blight, since the aerial survey as well as a series of earlier aerial surveys made by the Wisconsin Conservation Department showed the location of the outer limits of severe blight.

The results of the appraisal survey were essentially identical for all maple blight areas. At the time of the initial appraisals in 1958, the general opinion of those making the survey was that the blight was not spreading outward into surrounding healthy stands. A rechecking of the painted boundaries on the small maple blight areas in 1959 and again in 1960 indicated no spread whatsoever. A subsample of the transects on the large maple blight area in Florence County in 1959 and 1960 also showed no evidence of spread. Not all of the transects were rechecked because the evidence showed no need for it.

In 1958 when the first appraisals were made it was not possible to be certain whether blight was intensifying on the previously affected areas. In general, however, the current symptoms found on damaged but still living trees seemed to be the result of previous damage rather than intensification resulting from current activity of the causal agent of blight. Subsequent observations on the small maple blight areas in Iron and Ashland Counties

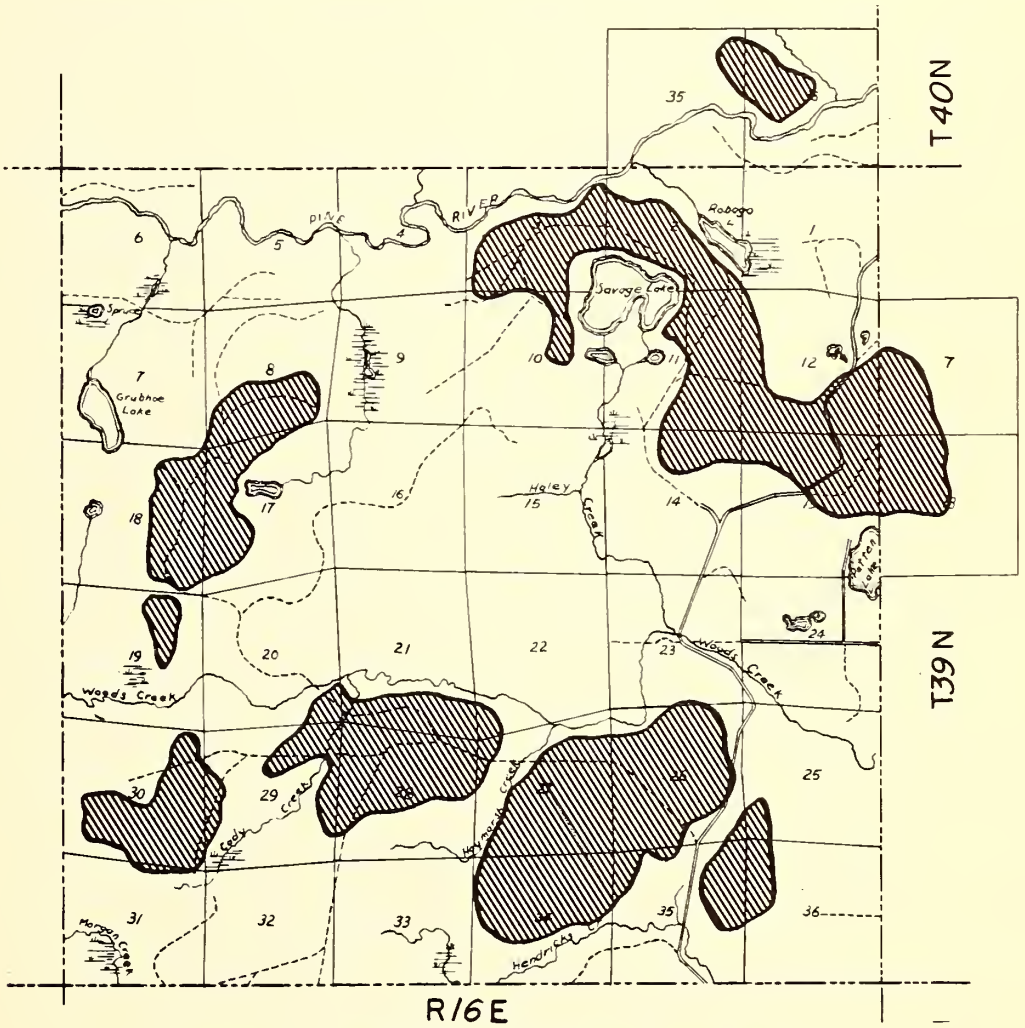

FIGURE 4. — Local distribution of maple blight, Florence County, Wis., 1958.

in 1959 and 1960 showed no evidence of current intensification. Instead, the picture was one of recovery for those trees that had not been killed. Reexamination of plots established by the research workers in their studies on the Florence County area presented the same picture — that is, recovery, not intensification — except for a few individual trees where the continued decline was shown to be due to secondary factors.

A third finding was that all of the areas affected by maple blight had also been infested previously by defoliating insects. In the small maple blight areas the major portion of the damage had occurred in 1957. This agreed well with results obtained by Houston in his disease studies in Florence County (discussed later).

The principal conclusions arrived at from the appraisal survey were as follows:

1. Maple blight symptoms were never found in any area that did not have a history of insect defoliation.

2. In all of the maple blight areas a major portion of the damage and mortality had occurred in 1957, and subsequent to that the picture had been one of recovery.

3. The failure of maple blight to spread and intensify suggested that maple blight was not caused by a highly virulent pathogen.

DEFOLIATION STUDIES[2]

For a variety of reasons all of the research studies conducted on the maple blight problem involved defoliation. Defoliation is the key factor in the development of the maple blight complex. For this reason, research on defoliation is discussed early in this report to orient the reader properly on its significance and to better enable him to interpret its relationship to the other factors on which research was conducted.

The maple blight area in Florence County had been subjected to severe insect defoliation from 1955 to 1957. By 1958, however, when research studies were started, the insect population had collapsed. To study the effects of defoliation under controlled conditions it therefore was necessary to resort to artificial defoliation.

Giese and Kapler's studies were aimed at determining the response of maple to defoliation and whether such defoliation could cause the development of maple blight symptoms. They established a number of defoliation studies during 1958, 1959, and 1960. The principal study was conducted on a stand of saplings growing under a closed overstory. Treatments included complete defoliation, defoliation of the upper two-thirds of the crown, defoliation of the lower two-thirds of the crown, defoliation of the upper one-third of the crown, defoliation of the lower one-third of the crown, and two sets of checks. Neither set was defoliated, but trees in one set were bent over and released in a manner similar to trees that were bent over for defoliation. Similar tests were installed in open-grown stands where maple saplings were the dominant tree cover, and also in a number of different geographic locations. In some of these studies trees were defoliated at weekly intervals throughout the growing season, and some selected trees were defoliated in 2 successive years during the same week of the year.

An additional type of treatment was introduced into studies established in 1960: Individual leaves scattered throughout the crown were removed on the basis of one out of every four, two out of every four, and three out of every four.

The response of sugar maple to defoliation was dramatic. As a result of a single complete defoliation or complete defoliation of a major portion of a tree's crown, all of the recognized maple blight symptoms were created. Except for maple defoliated later than mid-August, trees that were given major defoliation treatments refoliated; but usually such foliage was small and sparse. The year after treatment, those trees were characterized by wilting, severe dieback, heavy epicormic sprouting, and considerable tree mortality — all characteristic symptoms of the maple blight that had developed earlier from natural causes. Even when only portions of a crown were defoliated, those portions developed the blight symptoms.

[2] *Conducted by Drs. Ronald L. Giese and Joseph E. Kapler of the Department of Entomology, and Dr. David R. Houston of the Department of Plant Pathology, University of Wisconsin; and by Darroll D. Skilling, Lake States Forest Experiment Station.*

The principal conclusion is that severe defoliation of sugar maple for 1 year can cause symptom development that is identical with that described for maple blight. Some other interesting findings and conclusions are that defoliation late in the growing season does not cause severe damage; hence, timing of defoliation is critical to the development of blight-type symptoms. Another finding was that even 2 years after defoliation there is a continuing decline of affected trees. A second defoliation, however, 1 year after the first did not seem to increase appreciably the severity of symptom development. Neither did uniform removal of part of the foliage throughout the crown.

The reaction of sugar maple to a single defoliation was much more severe than most people (including entomologists) anticipated on the basis of previous defoliation studies on other species. Two important points are emphasized by this result. First, sugar maple apparently is much more susceptible to defoliation injury than are some other deciduous species; and secondly, timing of defoliation is closely related to the degree of damage caused. In particular, the timing of the defoliation by the insects involved in maple blight is such as to generate maximum damage.

Defoliation studies were conducted as a necessary adjunct to disease research efforts to determine whether a pathogen was involved in the maple blight problem. That is, the detrimental effects of defoliation on host trees could materially affect their response and susceptibility to invasion by pathogens. The studies also helped scientists to distinguish between such symptoms as could be attributed solely to defoliation from those which conceivably could be caused by a pathogen. Dr. Houston's studies did, of course, provide substantial evidence on the effects of defoliation itself. The results were essentially identical with those obtained by the entomologists in their studies.

Houston's defoliation studies were conducted on saplings, both open-grown and understory, and the defoliation schedules employed were very similar to those used by Giese and Kapler. Although the results of the two sets of studies were essentially identical, some differences in certain details provide additional information. Houston did defoliate some trees twice in the same year, and almost all such treated trees were dead the next year. He defoliated selected individual branches on maple trees, and symptom development on those branches was virtually the same as for entire defoliations or defoliations of major portions of the crown. He noted that the amount of terminal bud mortality increased with the date of defoliation from June to early August and then decreased, with the most severe bud mortality occurring on trees defoliated from mid-July to mid-August. Tree death was greatest in the series with the most bud mortality.

In September 1958, Houston observed that an early fall frost injured the new growth on trees that had refoliated; this substantially increased the injury caused by defoliation by destroying much of the bud tissue not yet mature enough to resist frost damage. This type of damage was much more severe on open-grown than on understory trees. His weather records show that temperatures went down much lower in open areas than under an overstory canopy during the fall-frost period. Apparently the effects of fall frost on refoliation tissue that has not yet hardened off may be an important contributing factor to maple blight. The reduced mortality and damage on trees defoliated during the latter part of the summer may be due to their failure to refoliate and, consequently, lack of new bud tissue to be damaged by frost.

Houston noted that mortality of treated saplings was not random among trees given any one treatment and considered this as evidence that a contributing factor other than defoliation may be involved in maple blight mortality. This provided a clue for some of his pathogen studies, which are reported in a later section of this paper.

A defoliation study was also conducted as part of Skilling's research to determine the role of other environmental factors as possible causes of maple blight. His primary purpose was to learn the interrelationships between maple blight and defoliation accompanied by reduced soil moisture. This study, which differed substantially from the other investigations, also provided considerable information on the effects of defoliation alone. The test trees were larger pole-sized trees in a dominant position in the forest canopy and were defoliated from a tractor-mounted ladder instead of by bending them over as was done with the saplings in the other studies (fig. 5). Also, all of his work was conducted on the Argonne Experimental Forest at a considerable distance from any area that had suffered from maple blight. Nevertheless, the results were

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FIGURE 5. — Defoliating a maple to study symptoms caused by defoliation.

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FIGURE 6. — Bunchy appearance of foliage on maple damaged by blight is caused by the fact that foliage is on epicormic sprouts. This is characteristic of trees during early stages of recovery.

essentially identical with those obtained by the other workers. His work also demonstrated that defoliation was *the* most important factor among those he studied in causing maple blight symptoms.

Thus, three essentially independent studies of defoliation of sugar maple all demonstrated that defoliation by itself could cause all of the symptoms associated with the maple blight problem and that, beyond reasonable doubt, defoliation by insects was the principal factor causing the maple blight outbreak. Furthermore, this reaction to defoliation applied to maples over a wide range of tree sizes of all crown classes and over a wide range of sites and environmental conditions. It also appears that refoliation and the consequent incomplete hardening off of buds in the fall made the maple susceptible to frost injury, further aggravating the situation. Circumstantial supporting evidence that defoliation was the primary factor causing maple blight was the fact that, following collapse of the insect populations on the maple blight areas, those trees that had not been killed outright were recovering (fig. 6).

DISEASE STUDIES[3]

The principal objective of pathology research on maple blight was to determine whether a pathogen is a primary factor in causing the disease. This was a key consideration. If a virulent pathogen was involved, there was a strong possibility that sustained spread and intensification would continue until maple blight had caused severe damage throughout major portions of the sugar maple type. On the other hand, if maple blight was not caused by a virulent pathogen, the odds were that (1) the causes involved were unique to certain local situations, and hence, maple blight had much less potential for intensification, or (2) the blight was caused by insects, in which case prospects for controlling occasional epidemics would be better than for a pathogen. Dr. Houston was given responsibility for resolving this important question.

There were two important phases to this work. The first required a careful study of symptom development on individual trees and in local stand areas to determine whether there was any characteristic pattern that provided clues as to the cause of the symptom complex. The second and key phase was to search for pathogens and to test their ability to cause maple blight symptoms on previously healthy trees.

There were several phases to the symptom development studies. The defoliation work previously described provided information on symptoms that could be attributed directly to defoliation damage. Plots were set up in the maple blight area to study the development and progression of symptoms on individual trees and in affected stands. Affected and healthy trees were examined biweekly and selected trees were photographed periodically to obtain a permanent record of symptom progression. The results indicated that most of the damage had been in the past; and there was little evidence of continuing or increasing damage. This, of course, was circumstantial evidence that minimized the possibility of a virulent pathogen being involved. There was some increase in damage during 1958, but this was relatively small compared to what must have happened in the preceding year. And in 1959 and 1960 some of the more severely affected trees died; but again these were relatively few compared to those that had died immediately following the insect defoliation.

Houston also determined what year most of the dieback had occurred in four different localities within the Florence County maple blight area. The time of major damage varied somewhat from one location to another, but the most severe symptom development had occurred during 1956 and 1957. This fits in very well with what most likely happened during the course of the insect epidemic; that is, there would be some variation in the time of onset of severe defoliation in different locales as the insect population built up. The general overall pattern noted in these studies coincides with the survey findings: the general picture following the initial severe damage 1 year after heavy defoliation was one of recovery and hence a strong indication that a virulent pathogen was not involved.

In 1958 when the studies were started it was not known, of course, that this pattern was going to develop. In any case, it still was desirable to make as certain as possible that no virulent pathogen was involved and to learn whether any pathogens, not of a highly virulent nature, might have contributed to the symptom development and mortality. Houston conducted isolation studies from all tissues of affected trees in a search for possible pathogenic fungi or bacteria. Repeated attempts were made from numerous trees and various parts of such trees. When these isolates were grown in culture and studied, none proved to be a fungus or bacteria previously known to cause a serious disease of sugar maple.

Cultures of the various organisms isolated were then used to inoculate healthy sugar maple in a location about 1.7 miles removed from any known maple blight. Inoculations were made at various conceivable points of entry by a pathogen, using a variety of inoculation techniques. None of the organisms tested produced maple blight symptoms. Aside from a little discoloration at the point of inoculation on some of them, the inoculated trees remained healthy.

Tests were also made to determine whether a virus might be involved. These tests were conducted by attempting to transmit mechanically any virus present from affected to healthy trees. Again no symptoms were produced; the possibility that a virulent pathogen was involved seemed small.

[3] *Conducted by Dr. David R. Houston, Department of Plant Pathology, University of Wisconsin.*

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FIGURE 7. — *Armillaria mellea* root rot on maple damaged by blight.

During his studies, Houston noted that on his defoliation plots mortality did not seem to be scattered at random among the trees given any one treatment but rather tended to appear in groups or pockets and that the mortality seemed to be concentrated in the vicinity of previously killed trees or stumps. This suggested that a root rot fungus such as *Armillaria mellea* (Vahl.) Quel. probably contributed to the mortality (fig. 7). The pockets of mortality were originally noted on the trees that were hand-defoliated in 1958. Repeated studies in 1959 and 1960 gave similar results. Examination of the roots and root collar region on these trees showed that *A. mellea* was very common on the dead and dying trees. Stumps of recently cut trees were studied to determine the pattern of *A. mellea* infection on larger trees. Of the maple blight trees salvaged in logging operations, about 70 percent were infected with *A. mellea*, whereas only about 32 percent of the "healthy" trees cut in logging operations were so infected. Houston concluded that, although defoliation is the principal cause of maple blight, *A. mellea* aggravates it or increases mortality and probably accounts for most of the delayed mortality. As previously noted, some mortality continued for about 3 years after the year of most serious damage.

In conclusion, it can be said that the results of the pathology studies supported the results found by others, which indicated that a primary pathogen was not responsible for maple blight. The studies also showed that Armillaria root rot contributed some increase in mortality among the trees weakened by insect defoliation.

The major role played by defoliation in causing maple blight indicates the importance of detailed knowledge about the insects responsible for the defoliation. Even though most entomologists and others were skeptical about insect defoliation being a major factor in the development of maple blight symptoms in Florence County, Wis., the fact that insect defoliation was coincident with maple blight indicated that the only wise course would be to give these insects major attention.

Giese made a detailed study of the defoliating insects that had been present on the area in large numbers during the period of severe defoliation. Three species of insects were primarily involved, two leaf rollers and a webworm. The following is a brief summary of what was discovered about each of these insects:

The first of these to appear during the growing season is a leaf roller named *Sparganothus acerivorana* MacKay. This is a solitary insect, with each individual rolling a leaf on a sugar maple. The insect had not been previously known to be present in this region. Since its discovery in the Florence County maple blight area, it has also been found in some other areas in Wisconsin. The larvae of the insect are solitary feeders and use the rolled leaf only as a retreat and a place for later pupation (fig. 8). They feed on adjacent leaves. Although a considerable number of leaves may be rolled by a high population of these insects, they do not seem to destroy enough leaves to damage sugar maple trees severely. This is true not only because of the number of leaves rolled but also because the affected leaves are more or less scattered throughout the crown. As was pointed out in the defoliation studies, scattered removal of individual leaves did not have much effect on the trees.

FIGURE 8. — Leaf roller, *Sparganothus acerivorana*, one of the three defoliating insects involved in maple blight. (Photo by Robert Martin, formerly with Goodman Division of Calumet and Hecla, Inc.)

The larvae of this insect have completed their feeding and pupate in late June through early July. The adults appear in late July, and mating and oviposition take place in that same season.

Twenty species of parasites were found on this insect. Of these, three species of Hymenoptera accounted for 95 percent of parasitization. The most important predators were spiders, reducing larval population more than all other predators combined.

In 1958 when the studies of this insect were initiated, the previous high population in the area had already collapsed; it is believed this collapse was due to predation and adverse weather conditions.

The second defoliating insect in the seasonal succession is another leaf roller named *Acleris chalybeana* Fern. This species also was previously not known to be present in the Lake States. Since its discovery on the Florence County maple blight area, it has also been noted in a number of other locations in Wisconsin. In many respects, its habits are very similar to those of the other leaf roller already described.

The larvae first appear from early to mid-June, largely in abandoned rolled leaves that were formed by *S. acerivorana*. This second leaf roller feeds in its roll; and once the food in that leaf is exhausted, it then feeds on adjacent leaves. Although in the early stages of its larval cycle this insect commonly uses abandoned leaf rolls, it also rolls its own leaves and thus increases the number of leaves rolled in a given maple stand; this has substantial significance as will be explained later. However, again the amount of feeding and leaf rolling done by this insect does not appear to damage sugar maple substantially in itself. These insects pupate,

[4] *Conducted by Dr. Ronald L. Giese, Department of Entomology, University of Wisconsin, presently on the staff of Purdue University.*

emerge as adults, mate, and oviposit during the same season as described for the other leaf roller.

Parasitism is an important factor, with losses from this cause sometimes accounting for as much as 90 to 99 percent of the larvae. Sixteen different parasites were found, and many of them were the same as those found on the other leaf roller. Predators are also important and probably can cause losses of about the same magnitude as the parasites. Again, spiders were the most common and important predators.

A third leaf roller named *Gracilaria* sp. was also found on the area, but there is no record indicating that this species occurred in high numbers during the period of defoliation that led to development of maple blight.

The third and last of the important defoliating insects to appear during the season is the maple webworm *Tetralopha asperatella* Clem. This insect can attack a number of hardwood hosts, but in the maple blight studies practically all of the defoliation observed was on maples. The maple webworm is a colonizing insect causing major defoliation — that is, removing the foliage almost completely from entire crowns of trees or major portions of crowns when the population is high. It is believed, therefore, that the direct cause of maple blight symptoms that can be attributed to defoliation is a consequence of feeding by the maple webworm.

The first webworm eggs are deposited from mid-June to early July and may continue to be deposited over a period as long as 60 days. The major peaks in egg abundance occurred in early July followed by another peak in late July. A very significant finding was that the only place in which eggs were deposited was in leaves rolled by the leaf-rolling defoliators. Hence, there appears to be a very close tie-in between the two types of insects; that is, evidently a population of leaf rollers is required on an area before there can be any substantial buildup in the population of webworms. Therefore, even though webworms do the damaging defoliation, the leaf rollers are of critical importance because they provide the necessary environment for deposition of webworm eggs and development of the larvae.

To begin with, the webworm larvae feed as leaf skeletonizers on the rolled leaf in which the eggs were deposited. The larvae then act as true webworms by webbing groups of leaves together. In later stages they feed voraciously, and large numbers of leaves are included in the web. Toward the end of the feeding activity, whole branches may be webbed by a single colony. The larvae of this insect, on the average, feed for about 45 days.

Some environmental factors were noted to affect webworm feeding. Webworm development was earlier and more rapid and populations were greater on the more exposed areas than in denser stands where crown closure was nearly complete. Apparently stand openness favors development of populations of this insect. In one area studied, as many as 63 percent of the saplings in the more or less open areas supported webworm colonies; whereas in nearby areas, which were much more densely stocked, less than 1 percent of the saplings were infested. Evidently the higher temperatures in these more open areas permit the insect to complete its life cycle more rapidly before a killing frost. This probably enhances buildup of populations in such areas.

The insect overwinters as a cocoon in the ground, and most of the adults emerge from mid-June to early July. Actually, in 1958 adults emerged over a 60-day period, starting about the first of June; and about 90 percent of the egg laying had been completed by August 15. The long period of time over which adult emergence and egg laying can occur poses problems with respect to any direct control measures that might be contemplated.

Parasites and predators of this insect were also studied. It was found that one species of parasite may parasitize as much as 17 percent of the eggs when there is a high population density. Several parasites and predators are also found to be active against the larvae.

Unquestionably, the maple webworm is the most important sugar maple defoliator with respect to the cause of maple blight. But probably the most significant discovery is the close interrelationship between the leaf rollers and development of a webworm outbreak. The studies indicated that as many as 200 webworms may develop from one rolled leaf.

A general study was also made of insects associated with rolled leaves. This microhabitat proved a favorite one for sucking insects. If a pathogenic virus is ever discovered on sugar maple, it is possible that the rolled-leaf community might well be important with respect to vector transmission of such a virus.

General insect populations present on blight areas as compared to nonblighted areas were sampled and identified. Dr. Roy Shenefelt of the University of Wisconsin did most of the identification work on these collections. Although a very substantial number of insects in great variety were found and analyzed, as of the present time none, aside from the defoliators, has been found to have any close relationship to the development of maple blight. Some of the insects encountered were attracted by the dead and dying trees and are of some importance in the more rapid deterioration of killed timber.

As a consequence of the insect studies made on the maple blight project, the role of defoliators is now well understood; and important complex interrelationships between the various species have been revealed. An important question is posed by what should be done in the event of future outbreaks of these insects that might lead to another maple blight situation. No control studies have been made, largely because of the lack of an outbreak population to work with. The situation appears very complex because of the number of species involved and the extended periods of oviposition and emergence of larvae. If another outbreak occurs, research should attempt to develop control measures.

ECOLOGICAL STUDIES[5]

In addition to insects and disease organisms, other factors in the environment were considered as possible primary or contributing causes to the development of maple blight. Skilling undertook studies in this area, with primary emphasis on the influence of physical factors in the environment, such as stand and site characteristics, and stand history. In 1958 in the Florence County maple blight area, he established a series of fifth-acre plots at 5-chain intervals along random lines running from healthy portions of stands to areas severely affected by maple blight. He established 113 plots. On each plot detailed descriptions were made of stand and site characteristics, history of the area, and the severity of maple blight.

A few of the factors studied did show a relationship to the severity of maple blight. One of these was stand density. About 70 percent of the maple trees on areas of low stand density had severe symptoms compared to 22 percent on areas with high stand density. Density as used here refers to the basal area of the stand. Most of the high prevalence of severe damage was in areas with less than 100 square feet of basal area per acre prior to any salvage operations made as a consequence of maple blight. There also was a relationship with number of trees per acre, stands with more stems having less damage. However, this relationship was not as pronounced as that based on basal area.

Skilling also found a relationship with stand composition; that is, severe maple blight was much more prevalent in those stands in which sugar maple made up more than 50 percent of the volume. In other words, maple blight was less severe in the more mixed stands.

Although the above relationships existed with reference to stand density and composition, some severe damage was found under all conditions. These relationships probably reflect the favorability of the various stand conditions for development of large populations of the defoliating insects.

No relationship was found between tree size, tree age, or site index and susceptibility to maple blight damage. Skilling also examined 20 sample plots that were established in 1948 by the owners for other purposes, on which each individual tree had been classified as to tree vigor. In his reexamination in 1958 there was no relationship between current severity of blight and vigor of trees as recorded 10 years earlier. This also was in line with general observations on the maple blight area at the time of the epidemic.

A detailed study of growth trends on 34 trees indicated no reduction in rate of growth prior to the onset of insect defoliation and maple blight. Apparently there had been no predisposing debilitating factors. Skilling and others also noted that the ground vegetation situation was quite different on severe blight areas than in normal stand situations in that there was a much denser growth of

[5] *Most of the ecological studies were conducted by Mr. Darroll D. Skilling, Lake States Forest Experiment Station.*

some of the ground cover species, such as raspberry. This relationship, however, is believed to be a matter of insect defoliation and maple blight mortality opening up the area, thus making the area more conducive to growth by these species.

A comparison of the cutting practices on various areas under study indicated no relationship between previous logging history and development of maple blight; some areas that had not been cut for 20 years had heavy maple blight mortality, and so did areas that had been cut quite recently. No abnormal amount of logging damage was found on blighted trees nor was there any evidence of fire, windthrow, or sunscald being associated with prevalence of maple blight damage.

Skilling also studied the influence of topography. Considering the relative elevation of each plot to the surrounding area, he found that blight was more severe on what can be referred to as upper flats where about 65 percent of the maple had severe blight; whereas on slopes and lower flats about 40 percent of the maple had severe blight symptoms. He did not find any relationship with aspect or degree of slope. The reason for more blight on upper flats is not definitely known. However, the differences involved with respect to topography and severity of maple blight do not appear to be strong enough to be considered as major factors in the problem.

Climatic factors were also considered. Records were studied from three weather stations. One of these is 13 miles northeast of the blight area, another 9 miles southeast, and the other one 9 miles west. The only suggestion of a weather influence was the fact that in the 10-month period prior to the onset of the severe mortality in 1957, precipitation was 8.3 inches below normal. This opened up the possibility that below-normal moisture could be involved in the development and severity of blight symptoms.

In preceding sections of this report it was suggested that early fall frosts or unusually severe frosts might be responsible for much of the bud dieback that occurs on refoliating trees. The weather records did not show any such frost for 1956 or 1957. However, these weather records do not necessarily establish that such a frost did not occur in the blight area, because such effects are often very localized. Much other evidence suggests that frosts, whether abnormal or normal, very likely do damage buds of trees that have refoliated.

Soil factors were also studied. A substantial number of soil samples, taken from four general locations in the maple blight area, were analyzed. This analysis showed no deficiences in soil nutrients or soil properties, but rather that the soil should be considered as a good hardwood soil. Some fertilization studies were also made on the maple blight area, but no differences were noted in the recovery pattern on these trees as compared to check trees which had received no fertilization.

Houston in his studies of possible pathogens established several plots to observe symptom development. These plots also provided some information on ecological factors. The data indicate that blight was more severe in low-density stands and in stands with a high proportion of sugar maple. Thus, his results in this respect substantiate those found by Skilling. Houston also pointed out that weather records obtained from some of his study areas showed that temperatures during frost periods run lower in more open-grown stands than under closed canopies. This is in line with the general pattern that has been found in the Station's studies of microclimate in relation to white pine blister rust.

In 1959 Skilling started a second major study in which the primary objective was to determine the influence of reduced soil moisture on development of maple blight symptoms. This study was established on the Argonne Experimental Forest, which is about 50 miles west of the Florence County maple blight area; therefore the study was not confounded by natural blight effects in the study area. By 1959 it was well recognized that insect defoliation was possibly a major factor accounting for the onset of maple blight symptoms. Therefore, defoliation had to be taken into account in evaluating the effects of reduced soil moisture. Skilling selected a number of test trees (which have already been referred to in the section of this report pertaining to defoliation studies) and applied various combinations of defoliation and soil moisture reduction; untreated trees were left as checks. A rather complex experimental design was used to enable the investigator to distinguish between effects caused by defoliation alone, by soil moisture reduction alone, or by the two in combination.

Soil moisture was controlled by digging a trench around a tree near the crown periphery and covering the area between the trench and the trunk of the tree with a moisture intercept

barrier. Some of these barriers intercepted and removed all moisture, others only 50 percent. This moisture-control system was put into effect in June of 1959, and the trees were defoliated in August of 1960. Soil moisture was measured periodically to determine the level of moisture prevailing around the roots of each of the trees in the test (fig. 9). Rootlet mortality was also checked in 1961 by sampling feeder roots from each of the trees. The principal problem was that soil moisture under the barriers was not reduced as much as had been anticipated, apparently because of some recharge from below. However, significant reductions in soil-moisture levels were eventually achieved.

The results showed that insect defoliation was definitely the most important of the factors causing maple blight but that reduced soil moisture did contribute by causing some increase in severity of symptoms; that is, trees subjected to a given level of defoliation plus reduced soil moisture had more severe symptoms than trees with the same defoliation but normal soil moisture levels.

In conclusion, it can be said that environmental factors do influence the severity of maple blight and the prevalence of maple blight symptoms, the principal factors being stand density, stand composition, and reduced soil moisture. However, all of these factors are definitely secondary to insect defoliation. The stand density and composition influence, of course, is believed to be indirect in that it affects insect population buildup.

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FIGURE 9. — Taking samples from soil beneath a rain intercept barrier to determine soil moisture level.

Lake States Forest Experiment Station.

1964. The causes of maple blight in the Lake States. Lake States Forest Expt. Sta., St. Paul, Minn. 15 pp., illus. (U.S. Forest Serv. Res. Paper LS-10)

This paper is a final report on the studies of maple blight in Wisconsin. It includes a description of the complex cooperative arrangements for conducting the studies. Survey results are presented and the research on insects, diseases, and ecological factors, published in detail by the University of Wisconsin, is summarized. Maple blight was found to be very limited in distribution and not spreading or intensifying. The principal cause is insect defoliation during a critical period in July and early August. A complex interrelationship was found between the various species of defoliators. Other factors that contribute to the severity of damage are Armillaria root rot, drought, low density, and a high proportion of maple in stands.

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